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genetic aberrations within the progeny of irradiated species of fruit flies. Moreover, the changes seemed to be linearly related to radiation dose; were cumulative; and were not reversible (14).

Muller's work went largely unnoticed until shortly before World War II when scientists associated with American atomic energy research began to worry about the genetic effects of ionizing radiation received by large population groups. At the same time, interest in the somatic effects of ionizing radiation, including the development of malignant disease, was rekindled. Since then, studies of Japanese nuclear bombing survivors and of various clinical groups exposed during multiple x-ray procedures have added greatly to our knowledge of the small-dose effects of ionizing radiation.

In chest x-ray examinations, radiation hazards are fortunately small. With respect to possible genetic damage, the amount of radiation reaching the testes in men and the ovaries in women is vanishingly minute as long as examinations are carried out with the x-ray beam limited to the thorax (chest) by collimation. Collimation is widely used in practice today and is a requirement of all NIOSH providers.

With respect to possible somatic damage, chest x-ray examinations deliver relatively small doses of ionizing radiation to the thorax due to the low density of the air-containing pulmonary tissues. As a consequence, approximately 20 posteroanterior radiographs of the chest may be performed on an individual in a given year, with the delivery of a mean radiation dose to the intrathoracic tissues no greater than that received annually from natural background sources at sea level. Although unnecessary radiation is something to be avoided at all times, present knowledge indicates that radiological examinations of the chest, judiciously planned and executed, do not constitute a significant hazard to health.

TECHNICAL ASPECTS OF RADIOGRAPHY

The Formation of Radiographic Images

X-ray Production

X-rays are produced whenever electrons impinge on matter at high velocity. To take advantage of this phenomenon, an x-ray tube consists of an evacuated glass envelope in which are mounted a source of electrons and a metallic target on which the electrons can be projected. Conventionally, the electron source is a filamentary wire which, when electrically heated to incandescence, emits electrons into the surrounding vacuum. These electrons are attracted to the target and x-rays are generated when a high electrical potential (several kilovolts), positive in polarity, is applied to the target.

In radiography of the chest, x-ray tubes must be operated at very high capacity. This is to assure that exposure times will be sufficiently short (e.g., 1/60 sec.) to avoid blurring of the radiographic images from heart motion. This requirement creates serious problems for the x-ray design engineer because x-ray production is a relatively inefficient process. Only a small fraction of the electronic energy developed in an x-ray tube is converted to x-radiation. The remaining energy is converted to heat, and when a tube is operated at high capacity, means of dissipating this heat must be provided before damage to the tube occurs. The problem is made particularly difficult by the fact that the tube's electrons must be focused on a very small area of the target (e.g., 1.5 mm sq. or less) if the radiographic images of all structures, both moving and stationary, are to be clear and sharp.

Because of these considerations, the targets of today's x-ray tubes are made of tungsten, a metal that is not only a relatively efficient x-ray emitter but a metal that has a high melting point. Moreover, the tungsten is arranged in the form of a disc which rotates in front of the electron source in a manner such that electrons fall successively on different areas of the disc during x-ray emission. Heat is thereby distributed over a large area of the target while x-ray emission appears to occur from a fixed locus. By these provisions, x-ray tubes with small focal spots can be operated at high capacity to yield x-ray images of excellent quality even in the presence of vigorous heart motion.

X-rays are emitted in all directions when electrons impinge on the target of an x-ray tube. For this reason, it is necessary to encase such tubes in leaded enclosures which prevent the escape of radiation except that coming through a small opening in the enclosure located close to the tube's target. This emerging radiation is further restricted by appropriate collimating devices—external to the tube—that prevent anatomical structures, other than those under examination, being irradiated. Moreover, aluminum filters, 2 mm to 3 mm in thickness, and placed directly in the emerging x-ray beam, remove components of the radiation which do not contribute significantly to the formation of x-ray images but which otherwise would add to the radiation dose received by the subject under examination.

Image Formation

Although x-rays have the ability to penetrate matter, only a fraction of the radiation falling on an object emerges from the opposite side. The remaining radiation is either absorbed in or scattered by the object. The fractions of radiation transmitted, absorbed, or scattered by an object (such as an anatomical structure) depend on the density and thickness of the structure its elemental composition, and the energy of the photons comprising the x-ray beam. Consequently, the x-rays transmitted by an object bear an image of the object's internal components.

For example, when x-rays are projected through a person's chest, the amount transmitted in the regions of the lungs is relatively large, because only small fractions of the incident radiation are absorbed or scattered by the air-containing pulmonary tissues. On the other hand, the amount of radiation transmitted in the region of the heart is relatively small, because the heart and its contents are quite dense. The radiation transmitted by the ribs is smaller still, because ribs contain calcium salts which absorb incident radiation to a much greater degree than the surrounding tissues, despite their short path length.

If the radiation transmitted by the chest falls on a photographic film, a visible image is created when the film is processed, with the areas of the film under the lungs being relatively dark and the area under the heart much lighter. Images of ribs superimposed upon the lung fields and heart are comparatively lighter still.

In addition to gross outlines of the lungs, heart, and ribs, fine detail within these structures can also be recorded if the x-ray tube has a small target area from which x-rays are emitted (i.e., a small focal spot); is operated with a short exposure time; and is placed a long distance (e.g., six feet) from the patient and film. Under these circumstances, images of the lungs' branching blood vessels can be recorded, appearing as relatively light structural patterns against the dark background of the air-filled pulmonary tissues.

No images of the peripheral bronchi or of their branches are seen under normal circumstances. Because these structures are air-containing, they transmit the same amount of x-rays as the lungs' air sacs; hence, no images of them are produced. However, if the air sacs contain fluid (as in pneumonia), and consequently become dense, the air-containing bronchi then create images that stand out in sharp contrast to those of the surrounding air-filled lung.

Recording Media

Photographic films, including those developed specifically for the recording of x-ray images, absorb very little of the x-radiation projected on them (about 2%). Consequently, large amounts of radiation are needed to produce satisfactory radiographic images unless some means is provided to make greater use of the available x-ray energy. Intensifying screens constitute just such a means. They are thin, yet rigid, sheets of radiolucent material, the size of an x-ray film, which are coated with a thin layer of fluorescent material composed of heavy-element crystalline salts whose x-ray absorption is relatively high (30% or more).

X-ray film, unlike conventional photographic film, is coated on both sides. Intensifying screens are normally produced in pairs, with one screen placed in apposition to the front surface of an x-ray film and the other in apposition to the film's rear surface. This duplication of screens increases the efficiency of x-ray capture. When exposed to x-rays, the intensifying screens fluoresce, converting the absorbed x-rays to light. The light then exposes the film.

A wide variety of films and intensifying screens are available to the radiologist. These range in sensitivity or speed from very slow, which require the delivery of a relatively large radiation dose to a patient, to very fast, requiring the delivery of a relatively small dose. In general, a film-screen combination's resolution (i.e., ability to record fine detail) varies inversely with its sensitivity or speed. In chest radiography, particularly when pneumoconiosis is a possible diagnosis, it is usually advisable to employ medium-speed films and screens. Such a combination should record the images of small pneumoconiotic lesions with sufficient detail to assure their easy recognition and yet not cause the de-

Table I-54
REPRESENTATIVE FILM-SCREEN COMBINATIONS OF THE MID-SPEED CLASS, SUITABLE FOR RADIOGRAPHY OF THE CHEST

Film	Screens	Rel. Speed#	QMI*
Class A	DuPont Par Speed	0.40	2.8
Class A	G.E. Blue Max I	1.00	4.2
Class A	Kodak X-Omatic Reg.	0.80	4.2
Class A	USR Rarex BG Detail	0.50	2.7
Class B	DuPont Par Speed	0.80	3.9
Class B	G.E. Blue Max I	2.00	6.0
Class B	Kodak X-Omatic Reg.	1.60	4.6
Class B	USR Rarex BG Detail	1.00	3.8
Class C	Kodak Lanex Fine	1.00	5.5
Class C	3_M Alpha—4	1.50	4.9
Class D	Kodak Lanex Fine	1.30	6.3
Class D	3_M Alpha—4	2.00	5.7

*Quantum Mottle Index, a measure of film granularity due to the discreet nature of x-ray photons.
Class A Films:—DuPont Cronex 7, Kodak XG
Class B Films:—DuPont Cronex 4, DuPont Cronex 6+, Kodak XRP and 3M, Type R
Class C Film:—Kodak Ortho G
Class D Film:—3M, Type XD
#Measured as the reciprocal of the radiation exposure in milliroentgens required to produce an optical density of 1.0 in the processed film.

livery of large radiation doses to patients.

Table I-54 lists a number of film-screen combinations of the mid-speed class that are suitable for chest radiography (15). Many physicians and technologists prefer combinations using class A and class B films because of the greater number from which to choose. Moreover, these films are sensitive only to blue light, in contrast to the green-sensitive class C and D films. Darkroom fogging tends to be encountered less frequently with such films.

Table I-55 lists the gradient and latitude characteristics of the films included in Table I-54. The gradient of a film is a measure of its contrast-recording ability. Latitude is a measure of the extent to which technical errors of exposure may be made without causing deterioration of image quality. These two parameters vary inversely with one another, i.e., films with high gradients generally exhibit less latitude than those with low gradients and vice versa.

Table I-56 lists resolution and absorption characteristics of the intensifying screens included in Table I-54. Resolution is a measure of a screen's ability to record detail; absorption a measure of the amount of radiation available for image production. It is wise to use screens with a high percentage absorption, so long as resolution is not sacrificed, because the radiation dose delivered to a subject during radiography is inversely related to the amount of radiation absorbed by the intensifying screens.

Generally speaking, it is desirable to use

Table I-55
CHARACTERISTICS OF REPRESENTATIVE FILMS OF THE MID-SPEED CLASS

Film	Gradient	Latitude
DuPont Cronex 4	3.0	0.58
DuPont Cronex 6+	2.6	0.67
DuPont Cronex 7	3.0	0.58
Kodak XG	3.0	0.58
Kodak XRP	2.8	0.62
Kodak Ortho G*	2.4	0.73
3M Type R	2.4	0.73
#M Type XD*	2.9	0.50

*Green sensitive, for use with green emitting screens.

Table I-56
CHARACTERISTICS OF
REPRESENTATIVE INTENSIFYING
SCREENS OF THE MID-SPEED CLASS

Screens	Rel. Resolution	% Absorption
DuPont Par Speed	1.4	21
GE Blue Max I*	1.5	32
Kodak Lanex Fine*+	2.1	34
Kodak X-Omatic Reg.	1.5	37
3M Alpha—4*+	1.7	42
USR Rarex BG Detail*	1.4	34

*Rare earth screens; +green emitting screens.
**These values apply to conditions in which an 80 kVp x-ray filtered with 3.5 cm Al, is used.

film-screen combinations with relative speeds ranging from 1.0 to 2.0, with quantum mottle indices of 5.0 or less and with screen absorption values of 30% of more. Under these conditions, the clarity of recorded images should be excellent and subject exposure small.

Image Quality

Image quality is the attribute of a radiographic film denoting the clarity with which recorded images are perceived, and hence, is as much an attribute of the observer as of the roentgenogram. Image quality is governed by a large number of factors, including characteristics of the structure under examination, a number of physical factors associated with the exposure, processing and visualization of the radiographic film, and the educational background and psychological state of the observer. Although many of these factors can be measured objectively, image quality is a parameter amenable only to subjective measurement due to the psychological element involved in its evaluation. Hence, the image quality of a particular radiograph may be perceived quite differently from one observer to another. This obviously creates problems for the technologist who serves a group of physicians, or who makes films that may be reviewed by a number of observers. Frequently, a film is judged acceptable by one physician, only to be rejected as unreadable by another. Image quality appears to bear a strong, inverse relationship to the interpretive difficulty a physician experiences with pathological changes recorded in a film. Often, films of excellent quality on purely technical grounds are rejected as "unreadable" when they contain patterns difficult to evaluate clinically.

So image quality is a parameter of enormous complexity. The more important aspects of the way radiographic technique can be used to enhance the quality of images seen in chest radiography follow:

Image Detail and Contrast

Two of the principal factors controlling image quality are the detail and contrast with which images are recorded. For purposes of this discussion, image detail is defined as the minimum limit of image size perceptible in a film. For radiographic films made with medium-speed intensifying screens, this limit is a diameter of 0.1 to 0.2 mm *when the images are of high contrast,* and when films are made under ideal technical conditions. Image detail is considerably poorer when images are blurred by movement of anatomical structures under examination, or by the use of an x-ray tube whose focal spot is excessively large. Image blurring and degradation also occur if the intensifying screens of a film-screen combination are not in uniformly firm contact with the film.

Image detail is also affected by image contrast, decreasing as contrast diminishes. In radiography, it is convenient to recognize two types of contrast: specific and gross. Specific image contrast is the difference between the blackness or optical density of the image of a given anatomical structure (or lesion) and the blackness or optical density of the immediate surrounding field. Gross image contrast, on the other hand, is the difference between the blackness or optical density of the darkest image of diagnostic interest in a film and the blackness or optical density of the lightest image of diagnostic interest.

Parenthetically, optical density is a quantitative measure of a film's blackness. Specifically, optical density at a given point in a film is the negative logarithm of the film's fractional light transmission. For example, a film which transmits one-tenth of the light incident on it has an optical density of 1.0; a film which transmits one-hundredth of the light has an optical density of 2.0.

Radiographic Exposure and Film Density

A radiographic film's blackness or optical density is a function of the x-ray exposure received by the film, rising from a value of zero, when no exposure is given, to values in excess of 3.0, when exposures are large (see Figure

I-15). This entire range of blackness or optical density, however, is not useful for clinical radiographic purposes. For example, if film receives an exposure (with characteristics shown in Figure I-15) of 1 mR directly under a subject's pneumoconiotic lesion, and the exposure received by the film from the region immediately adjacent to the lesion is 25% greater or 1.25 mR, the contrast between the lesion's recorded image and its surrounding field will be 0.3 units of optical density (Figure I-16). If the film under the lesion receives an exposure of 0.4 mR, the surrounding field receives 25% more or 0.5 mR. The contrast of the lesion's image under these circumstances will only be 0.15 units of optical density, due to the shallowness of the film's density vs log exposure curve at low exposure levels (Figure I-17). This loss of contrast is detrimental to image clarity and should be avoided. In practice, image contrast is usually judged unacceptable when a film's optical density is less than 0.2.

If the film under the lesion receives an exposure of 2.5 mR and the surrounding area 25% more or 3.125 mR, the image contrast will now be 0.275 units of optical density or closely the same as that when the exposure was 1 mR (Figure I-17). Under these circumstances, one might assume image clarity to be good. Such, however, is not the case under conventional viewing conditions. As images become darker, an observer's contrast discrimination diminishes noticeably. Moreover, even though the image contrast recorded by a film is good when the film's optical density is 1.7 or 1.8 and greater, the radiographic images are so dark that ambient light in the viewing room entering the observer's eyes and diffused by particulate material in the eyes, fogs the visual images and reduces their contrast to unacceptable levels. Ambient light in the viewing area should be maintained as low as possible. Otherwise, image contrast at the retina may fall to unacceptable levels at optical densities well below 1.8.

Useful Range of Optical Density

The useful range of film blackness for radiographic purposes extends from an optical density of about 0.2 at its lower limit to a density of 1.8 at its upper limit.* Such a range would be adequate for all radiographic purposes if, in practice, physicians were interested only in seeing images of simple anatomical structures, recorded one at a time. Under these circumstances, technologists would merely expose film to a point where a desired image produced (in the processed film) a density somewhere in the middle of the useful range and a good film would *a priori* be produced.

However, the chest is not a simple structure. It is extremely complex, and its radiographic images must be recorded all at once. Moreover, these images produce optical densities within the film that extend through wide limits. Hence, depending on what structures a physician wishes to see, a film's useful density range is often more than filled. For example, some physicians feel it would be desirable if, on a single film, one could record with excellent detail and contrast the images of the peripheral lung fields, the hilar blood vessels and lymph nodes, the heart and other mediastinal tissues, all of the osseous structures of the thorax and more. Unfortunately, this ideal cannot be reached because it is impossible to crowd images of all of these structures into the limited range of optical density available, and still retain levels of image contrast sufficiently high to permit these images to be seen well. Physicians must be satisfied with much less, and most find it acceptable if only images of the lung fields and hilar regions are included within the useful range of film density.

Because image contrast and clarity are closely related, it is generally important that as much of a film's useful range of optical density as possible be filled by images of diagnostic interest. Under these circumstances, both specific and gross image contrast levels approach their maxima. However, when the useful range is fully occupied, the technologist is left with little latitude in estimating the proper exposures to be given when radiographic films are made. Small errors of over- or underexposure will yield unacceptable films. Therefore, it is usually wise to limit gross image contrast to a level moderately below its maximum (i.e., moderately less than 1.6 units of optical density). Figure I-18 illustrates the amount of latitude available to the technologist when the gross image contrast is 1.2 units of optical density. Even under these conditions, the technologist has relatively little latitude for error.

*Useful information is also recorded above a density of 1.8 and can be recovered with the use of a high intensity illuminator. However, this procedure is impractical when dealing with large numbers of films as in the interpretation of pneumoconiosis radiographs.

Scattered Radiation Effects

Under some circumstances, optical densities of images of diagnostic interest fall far short of filling the useful range of film density, due to the presence of one or more factors impairing image contrast. The most serious of these is scattered radiation which, when excessive, fogs the film and sharply impairs image quality.

Scattered radiation increases rapidly as patient size and thickness increase. To a lesser extent, scattered radiation levels become greater when the electrical potential (kilovoltage) of the x-ray tube is raised.

The amount of scattered radiation reaching a radiographic film can usually be reduced to acceptable levels by the use of a grid—a device composed of alternating sections of radioluscent and radiopaque materials—which attenuates the scattered radiation while allowing image-bearing x-rays to pass through. Scattered radiation can also be reduced by increasing the distance between patient and film, but this can cause loss of image detail and a disproportionate increase in the radiation exposure of the patient.

High Kilovoltage Techniques

In recent years, the electrical potentials or kilovoltages applied to x-ray tubes during chest radiography have been raised substantially to improve the image quality of pulmonary and other nonosseous structures. By the use of potentials of 300 kVp and more, in contrast to conventional voltages of 80 to 125 kVp, x-ray absorption of the ribs is sufficiently reduced, and the tendency of these structures to obscure underlying pulmonary tissues is almost wholly alleviated. This trend may be expected to continue.

Miscellaneous Factors Affecting Image Quality (also, see Table I-57)

This discussion of the technical aspects of chest radiography would be incomplete without mentioning the importance of a number of tech-

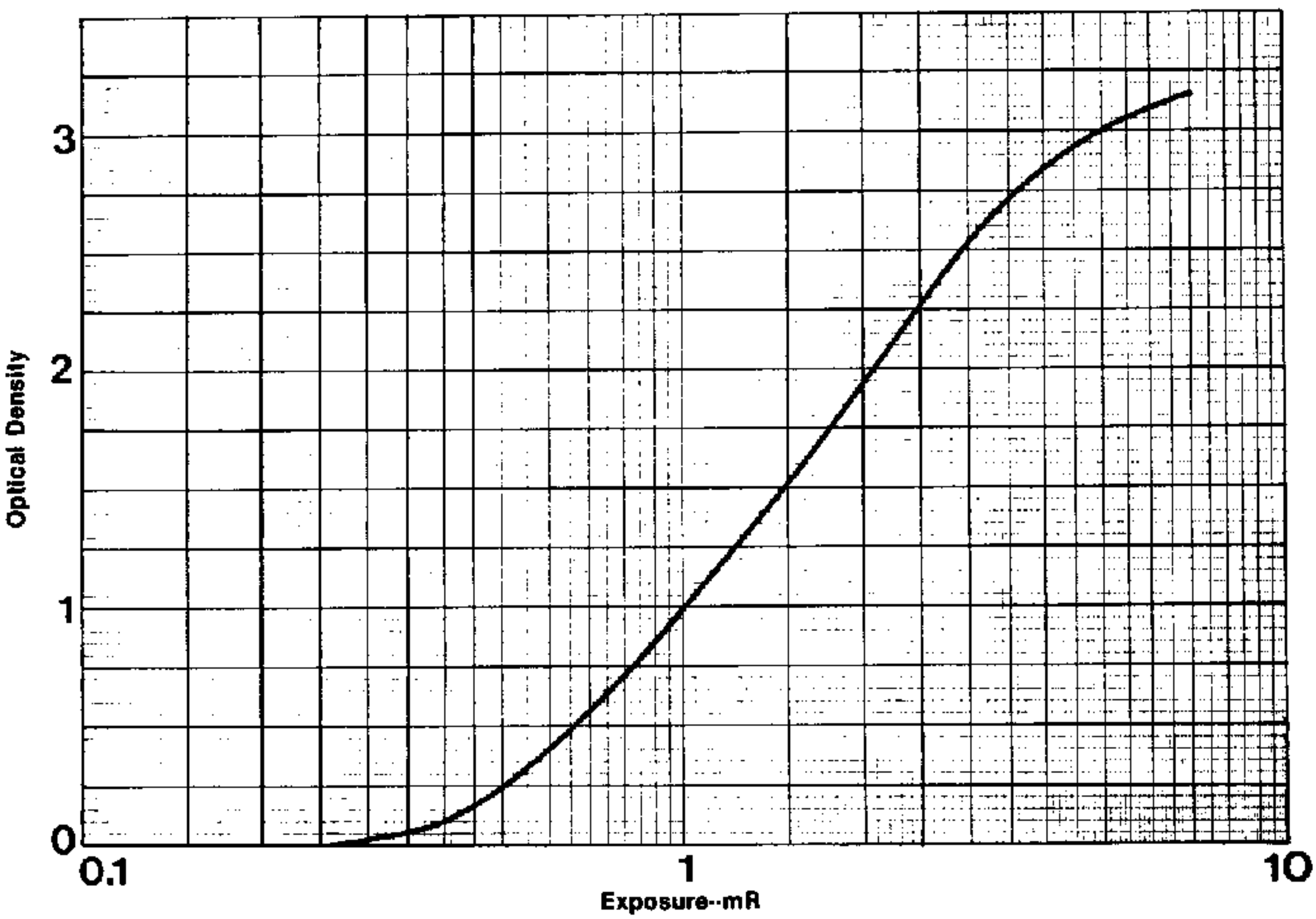

Figure I-15. Relationship between the exposure received by a typical film-screen combination and the optical density or blackness of the processed film.

Table I-57
CRITERIA FOR EXCELLENCE OF TECHNICAL QUALITY IN CHEST RADIOGRAPHS

The following rules may be helpful to those seeking technical excellence in radiography of the chest:

A. Optical Density

1. Hilar regions should exhibit a minimum of 0.2 units of optical density above fog.
2. Parenchymal regions should exhibit a maximum of 1.8 units of optical density above fog.

B. Gross Image Contrast

The difference in optical density between the darkest segment of the lung parenchyma and the lightest portions of the hilar region should fall within a range of 1.0 and 1.4 units of optical density.

C. X-ray Tube Potentials and Use of Grids

1. Potentials of 70 to 100 kVp: Use grid for all subjects whose posteroanterior dimension exceeds 22 cm.
2. Potentials over 100 kVp: Use grid for all subjects.

D. Exposure time: Not greater than 0.1 sec., and preferably 0.05 seconds or less.

E. Film-Screen Combination: Use medium-speed films and screens to assure adequate image detail. Good screen-film contact is essential; periodic testing mandatory.

F. Processing: Maintain strength and temperature of processing chemicals within limits recommended by manufacturer.

G. Assumptions

1. Cleanliness of films and screens and of processing fluids and equipment is maintained.
2. Care in subject positioning is taken.
3. Subject movement is prevented.

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nical requirements that must be met for the attainment of optimum image quality. One is the respiratory phase of the patient when a chest radiograph is made. It is essential that the patient be in deep inspiration with respiration arrested. This is to maximize image clarity and contrast and to reduce patient exposure. Films exposed during expiration or shallow inspiration are almost always unacceptable.

Another requirement concerns the position of the patient during exposure. He or she should be upright and placed facing the cassette in such a way that all portions of the lung fields, including the apices of the lungs, the lateral chest walls and the costophrenic angles, are recorded on the film. Moreover, the shoulders must be rotated forward so that the scapulae are moved to the sides and away from positions in which they obscure the lung fields.

Darkroom cleanliness and adherence to strict time-temperature processing is elementary but fundamentally important. All too often radiographic films are spoiled by poor darkroom technique. The repeated films occasioned by such spoilage represent the worst kind of unnecessary radiation exposure; radiation that with disciplined darkroom practices can be avoided entirely.

Major Problems in the Radiographic Technique

Experience gained from the pneumoconiosis programs of the National Institute for Occupational Safety and Health and of the Department of Labor, indicates that the most serious problem found by physicians and their technologists in producing satisfactory films of the chest is the estimation of proper radiographic exposure. There is little room for error when such estimates are made; overexposure or underexposure, with resultant loss of image quality, can easily occur.

The correction of this problem lies in improved training programs for both physicians and technologists. The need for professional excellence in radiographic technology cannot be overemphasized. Unfortunately, many of radiology's practitioners currently fail to recognize its importance.

Another technical problem, almost as serious as that pertaining to radiographic exposure, is the inadequate control of scattered radiation, particularly in large patients. Since satisfactory methods of control are readily available, this problem's correction seems to be a matter of improved training and supervision of radiographic professionals. When scattered radiation is not controlled properly, image contrast falls quickly to unacceptable levels.

Three other technical problems also reflect inadequate radiographic skills and/or lack of professional discipline and supervision among physicians and their technologists: unsatisfactory patient positioning, failure to correct radiographic cassettes in which there is poor film-screen contact, and failure to maintain minimum standards of cleanliness in the darkroom.

Taken together, these problems cause—in the best of settings—about 10% of chest radiographs to fall below optimal quality standards. In the worst situations, failure rates exceeding 50% are not uncommon.

STANDARDS OF INTERPRETATION AND CLASSIFICATION OF CHEST RADIOGRAPHS IN PNEUMOCONIOSIS

The Radiology of Pneumoconiosis (5)

When dusts containing one or more of the many compounds of silicon are inhaled, pathological changes occur within the lungs and pleural coverings that are detectable radiographically. As the dust particles find their way into the lungs' alveolar sacs, a localized reaction takes place about each particle or group of particles that ultimately leads to the formation of a small fibrous nodule. Such nodules appear in the lung fields of a chest radiograph as small discrete opacities, rounded and/or irregular in shape, a few millimeters in diameter, and distributed widely throughout the lungs.

When dust exposure is limited, the number or profusion of opacities is likely to be small and their distribution localized. However, if the exposure continues, the opacities will increase in number until ultimately, adjacent lesions coalesce to form large opacities several centimeters in diameter and often distributed widely throughout the lungs. At this stage, serious lung damage has occurred.

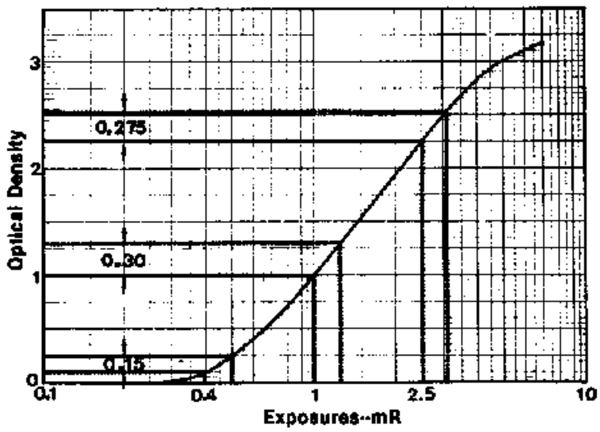

Figure I-16. Illustration of the effect of optical density on the contrast exhibited by an image recorded by a radiographic film.

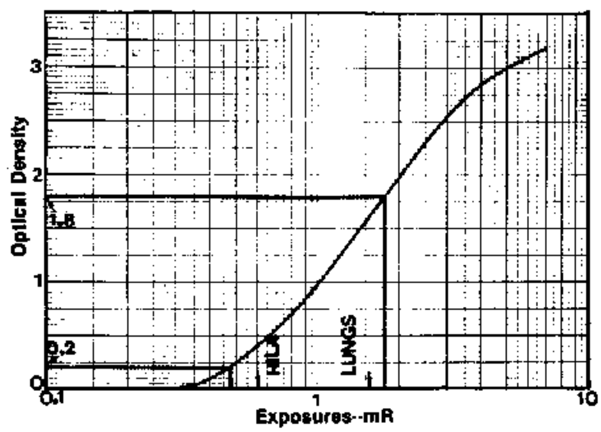

Figure I-17. Graphic illustration of how the latitude of a technologist in estimating the exposure to be given during radiography of the chest diminishes as the useful range of optical density becomes increasingly filled by images of diagnostic interest.

With many silicic materials, such as those encountered in coal mining, radiographic opacities tend to reside in the upper lung fields. In other cases, especially when asbestos fibers are inhaled, changes are more commonly observed in the lung bases and are more irregular or linear in shape. Asbestos fibers tend to migrate to pleural surfaces by way of lymphatic channels to create localized fibrous thickenings of pleural tissues. These lesions characteristically occur

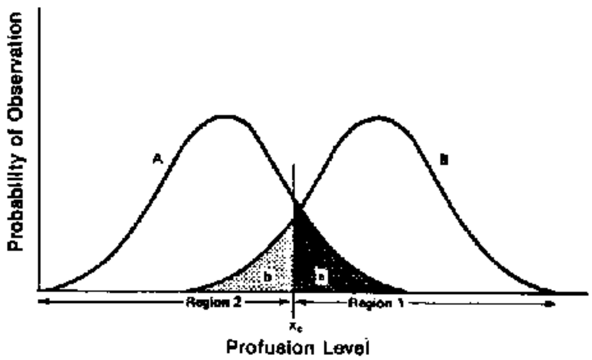

Figure I-18. Representation of the decision problem in pneumoconiosis. Hypothetical population distributions in which the ordinate depicts the probability of one's observing a given profusion level in a population free of pneumoconiosis (curve A) and in a population with pneumoconiosis (curve B).

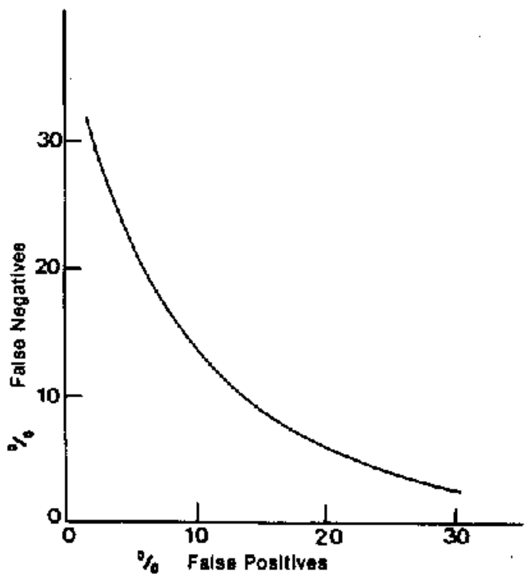

Figure I-19. Curve illustrating reciprocal relationship between percentage false negative and false positive interpretations of chest radiographs for pneumoconiosis (derived from data given in Figure I-18).

along lower chest walls, on diaphragmatic surfaces, and in pleural and pericardial surfaces adjacent to the heart. Frequently, they become calcified.

In advanced cases of pneumoconiosis, there is usually no question, radiographically, regarding the disease's diagnosis. However, when only small opacities are present and their profusion is limited, interpretation can be difficult (12). This is because small opacities can occur in a wide variety of situations, both normal and abnormal, as well as in pneumoconiosis. For example, as individuals become older, periodic respiratory infections often leave them with pulmonary fibrotic changes that appear radiographically as small irregular opacities. These changes are particularly prevalent in cigarette smokers. Also, individuals who suffer from congestive heart disease, in time, develop extensive fibrotic findings in the lungs that may be confused with early stages of pneumoconiosis. Finally, many pathological conditions unrelated to dust (e.g., sarcoidosis) manifest, at various times in their courses, radiographically as small opacities.

So radiographic findings in early pneumoconiosis are not unequivocally interpretative. This has led to the suggestion that chest radiographs always be evaluated with the assistance of the clinical information provided in the patient's history. Superficially, the suggestion appears to have merit. However, it must be recognized that such clinical data usually exhibit as many uncertainties as the radiographic findings. Hence, it is wise in most instances to evaluate history and radiography independently of one another and only afterward bring the two bodies of information together for a clinical judgment. Such a process tends to maximize clinical objectivity and minimize interpretative errors of the history and radiographic information.

Because of the difficulties that exist in the interpretation of chest radiographs, it is not surprising that inconsistencies arise when a number of physicians independently evaluate a series of radiographs or when an individual physician evaluates the series a number of times. Such inconsistency is unavoidable and indeed is characteristic not only of radiographic procedures but all clinical testing (including history taking, physical examinations, and physiological tests) due to uncertainties inherent in all methodologies in which human judgment is a factor (8)(19).

To illustrate graphically the manner in which interfering patterns affect the decision processes and observer error in the interpretation of chest radiographs for pneumoconiosis, consider the profusion of small rounded or irregular opacities (i.e., the number of opacities per cm²) that might be observed in the films of a representative sample of individuals who are free of the disease: Curve A, Figure I-18, plotting the number of films prevailing at each profusion level, depicts data that might result from such a study. The profusion of similar opacities in the radiographs of individuals who have pneumoconiosis are greater; the corresponding probability distribution generated by those cases might be characterized by Curve B. The two curves overlap and diagnostic uncertainty will prevail for cases included in the overlapping region. If an interpreter selects a profusion level of x_c as his operating point—separating cases he will call positive for pneumoconiosis from those he will call negative—cases to the right of x_c in region 1 will be called positive for the disease. Of these, the cases under the unshaded portion of Curve B will be correctly diagnosed; i.e., they will be true positives. However, cases included under the shaded portion of Curve A (a) will also be called positive, in spite of the fact that they actually are free of the disease. Such cases will, therefore, be false positives.

Cases to the left of x_c in region 2 will be interpreted as normal. Of these, cases under the unshaded portion of Curve A will be correctly diagnosed as negative, whereas those under the shaded portion of Curve B (b) must represent false negative interpretations, since disease is actually present in these cases.

It will be evident from an examination of Figure I-18 that the percentages of false positive and false negative interpretations will depend upon where the operating point (x_c) is placed. If it is placed to the left of the position shown, the number of false negatives will diminish but at the expense of an increasing number of false positives. If the operating point is moved to the right, the number of false positives will diminish but at the expense of an increasing number of false negatives. The reciprocal relationship between the percentage of false positive and false negative interpretations as one moves the operating point (x_c) along the profusion axis is illustrated graphically in the Figure I-19.

Significant inconsistencies among readers in the radiographic interpretation of pneumoconiosis have been documented (1)(2)(6)(7)(16)(17). Reger found that three American readers who interpreted 498 coal miners' radiographs of profusion according to the UICC Classification agreed as to the major x-ray category on 48% to 71% of the films, while on these same films five British readers agreed on 83% to 90% (3)(16). Felson similarly documented the level of agreement among readers who interpreted the radiographs of 55,730 coal miners examined under the Federal Coal Mine Health and Safety Act of 1969. Felson found the 'A' readers (the first readers to interpret the miner's X-ray) agreed with 'B' readers (members of radiology departments at three hospitals who were experienced at classifying pneumoconiosis) on 41,493 (74.5%) of the 55,730 films interpreted. In both Reger's and Felson's studies approximately 87% to 89% of the films were interpreted as normal.

Inconsistencies in radiographic interpretation can probably be reduced by multiple readings carried out independently by a number of physicians with results examined for consensus (18). Inconsistency can also be minimized by training programs in which physicians are taught to recognize subtle differences between normal and abnormal radiographs. Finally, it is important that physicians responsible for interpreting chest radiographs in national pneumoconiosis programs have opportunities to apply their knowledge sufficiently often to maintain diagnostic acuity. If these criteria are carefully observed, the chest radiograph can be relied upon to be of great value in the evaluation of individuals suspected of having dust-related disease.

ILO Classification System (9) (11)

In clinical practice, it is customary for physicians reporting radiological findings recorded in chest films to do so in nonquantitative, narrative form. For most clinical purposes this is satisfactory. However, when the information is to be used epidemiologically or to evaluate pulmonary disability in workmen's compensation programs, the reporting must be more quantitative.

The need for this was first recognized officially by the International Conference on Silicosis held in Johannesburg in 1930. Since then, the system devised during that meeting has evolved through a series of revisions until the current system, known as the ILO 1980 International Classification of Radiographs of the Pneumoconioses, was recently adopted by the International Labor Office in Geneva (9). The current system has been designed not only to permit codification of coal workers' pneumoconiosis (CWP) and silicosis but also of asbestosis. Expansion of the system to include the latter entity occurred in 1967 with the assistance of a subcommittee of the Committee on Asbestos and Cancer of the International Union Against Cancer (UICC), members of the McGill University Asbestos Study, and the panel of Radiology Consultants to the Bureau of Occupational Safety and Health, U.S. Public Health Service (USPHS) meeting in Cincinnati.

The ILO-80 Classification System requires the codification of a chest radiograph according to its pulmonary and pleural findings and to its technical quality. With respect to pulmonary findings, the system divides lung opacities into two categories: small and large with each defined in specific quantitative terms.

Small Opacities

The system requires the recording of data on the following four characteristics: shape, size, profusion, and extent. Two shapes are recognized; small rounded and small irregular. For each shape, opacity size is graded in three categories. For example, rounded opacities are classified according to the approximate diameter of the predominant lesions into:

(p) opacities up to about 1.5 mm in diameter

(q) opacities exceeding 1.5 mm and up to about 3 mm in diameter

(r) opacities exceeding about 3 mm and up to about 10 mm in diameter

Irregular opacities are classified according to the approximate width of the predominant lesions into:

(s) fine linear opacities up to about 1.5 mm width

(t) medium opacities exceeding about 1.5 mm and up to about 3 mm in width

(u) coarse, blotchy opacities exceeding about 3 mm and up to about 10 mm in width

To record shape and size, two letters must be used. If the reader considers that virtually all of the opacities are of one shape and size, this should be noted by recording the appropriate symbol twice, separated by an oblique stroke (e.g., q/q). If, however, another less predominant shape (or size) is observed, this should be recorded as the second letter (e.g., q/t). Hence, q/t would mean that the predominant small opacity is round and of a size q, but that significant numbers of small irregular opacities are present of size t. In this scheme, the recording of no more than two kinds of size and shape is permissible.

The term profusion refers to the concentration or number of small opacities per unit area observed within the lung fields. In early versions of the system, profusion was graded only in four major categories:

Category 0: small opacities are absent or less profuse than Category 1

Category 1: small opacities are present, but few in number; the normal lung markings (i.e., the images of the vascular structures) are usually visible

Category 2: small opacities are numerous; the normal lung markings are partially obscured

Category 3: small opacities are very numerous; normal lung markings are usually totally obscured

In 1968, this codification of small-opacity profusion was modified by the further division of each major category into three minor divisions to provide a 12-point scale or continuum. The current notation designating the several divisions of this scale is as follows:

0/−	0/0	0/1
1/0	1/1	1/2
3/2	3/3	3/+

The first number in each division indicates the major category to which the division belongs; the second number indicates whether the profusion level is judged to be somewhat less than, equal to, or somewhat greater than the profusion level corresponding to the major category indicated. Thus, the notation 2/1 is used to indicate a profusion level that is definitely category 2 but somewhat less than the midpoint of that major category.

Although this 12-point scale of profusion implies a high degree of quantification for the recording of profusion levels, the definition of the major profusion categories on which the scale is based is nonspecific. Hence, when the profusion levels of a series of radiographs are evaluated by a group of physicians, substantial differences of opinion can be expressed.

The problem is particularly bothersome when profusion levels are near the lower end of the scale. This is because films in major category 0 (i.e., profusion categories 0/ – , 0/0, and 0/1) are usually regarded as normal or as exhibiting essentially no evidence of pneumoconiosis, whereas films in major category 1 (i.e., profusion categories 1/0, 1/1, and 1/2) are generally regarded as poitive for pneumoconiosis. The radiological findings of pneumoconiosis in its early stages are difficult to differentiate from the findings of normal individuals. Both may have similar small-opacity profusion levels. Physicians generally have difficulty in separating a series of radiographs into normals and abnormals when profusion levels are near the divisions 0/1 and 1/0. A given physician will exhibit some inconsistency in his or her codification of profusion in such instances.

Physicians of limited experience, or physicians who do not have the opportunity to see (in their practices) the range of appearance normal films may exhibit, tend to codify their films into higher profusion levels than those classified by their more experienced colleagues. This circumstance constitutes a serious problem for administrators of workmen's compensation programs because consistency between readers is difficult to obtain when readers of different backgrounds and experience interpret films. It is a problem that can be resolved only by the development of improved training standards for all physicians involved in such programs and by the use of multiple readings to resolve interpretive differences when they occur.

The fourth characteristic of small opacities that must be codified in the ILO-80 Classification System is the spatial distribution of pulmonary disease. To record this parameter, lung fields are divided into six zones, three on each side, corresponding to the upper middle and lower thirds of the lung fields. In reporting the extent of disease, the physician simply checks off the zones affected.

Of the four characteristics of small opacities requiring codification, profusion is the most important for it is the best indicator of the seriousness of any disease that may be present. When profusion levels vary from one portion of the lung fields to another, the category of profusion to be recorded is determined by considering the profusion as a whole, over the affected lung zones. Where there is a marked (three minor categories or more) difference in profusion in different zones, the zone or zones showing the lesser degree of profusion are ignored for the purpose of classifying profusion.

Large Opacities

These lesions are codified in three categories of size:

Category A: a single opacity whose greatest diameter exceeds about 1 cm but is no more than about 5cm, or several opacities, each greater than about 1 cm in diameter, the sum of whose diameters does not exceed about 5 cm.

Category B: one or more opacities larger or more numerous than those in Category A whose combined area does not exceed the equivalent of the right upper zone.

Category C: one or more opacities whose combined area exceeds the equivalent of the right upper zone.

Pleural Thickening

With respect to pleural thickening, the ILO-80 Classification System requires that the site (chest wall, diaphragm, costophrenic angle), width, and extent of the thickening be recorded separately. In the case of site, pleural thickening of the chest wall must be recorded separately for right and left sides.

For pleural thickening observed in profile (edge on), width is measured from the inner border of the chest wall to the inner margin of the parenchymal-pleural boundary seen most sharply. The ILO system recognizes three gradations of width:

a. a maximum width up to about 5 mm

b. a maximum width over about 5 mm and up to about 10mm

c. a maximum width over about 10 mm

The presence of pleural thickening observed face on (en face) is recorded even if it cannot be seen in profile. If pleural thickening is observed face on only, width cannot be measured.

The extent of pleural thickening is defined in terms of its maximum length, whether seen in profile or face on. Three gradations of extent are recognized:

1. total length equivalent to up to one quarter of the projection of the lateral chest wall.
2. total length exceeding one quarter but not one half of the projection of the lateral chest wall.

3. total length exceeding one half of the projection of the lateral chest wall.

With respect to involvement of the diaphragmatic pleura, localized thickening (plaque) is recorded separately as present or absent, and right and/or left. Obliteration of the costophrenic angle is recorded in a similar manner.

When pleural calcification is observed, its site (chest wall, diaphragm, and other locations) and extent are recorded separately for the two sides of the thorax. Three gradations of extent are recognized:

1. a region of calcified pleura with a maximum diameter of up to about 2 cm or a number of such regions, the sum of whose diameters does not exceed about 2 cm.
2. a region of calcified pleura with maximum diameter exceeding about 2 cm and up to about 10 cm, or a number of such regions, the sum of whose maximum diameters falls within this range.
3. a region or number of regions of calcified pleura, the sum of whose maximum diameters exceeds 10 cm.

Obligatory Symbols

The ILO Classification System includes a number of symbols (whose use is obligatory) to permit the recording of important radiographic features (see Table I-58).

Table I-58

OBLIGATORY SYMBOLS

ax	—coalescence of small pneumoconiotic opacities
bu	—bullae
ca	—cancer of lungs or pleura
cn	—calcification in small pneumoconiotic opacities
co	—abnormal cardiac size and/or shape
cp	—cor pulmonale
cv	—cavity
di	—marked distortion of intrathoracic organs
ef	—effusion
em	—definite pulmonary emphysema
es	—eggshell calcification of hilar or mediastinal lymph nodes
fr	—fractured rib(s)
hi	—enlargement of hilar or mediastinal lymph nodes
ho	—honeycomb lung
id	—ill-defined diaphragm
ih	—ill-defined heart outline
kl	—septal (Kerley) lines
od	—other significant abnormality
pi	—pleural thickening in the interlobar fissure or mediastinum
px	—pneumothorax
rh	—rheumatoid pneumoconiosis
tb	—tuberculosis

Technical Quality

The ILO Classification System recognizes four gradations of technical quality as follows:

1. Good
2. Acceptable, with no technical defect likely to impair classification of the radiograph for pneumoniosis
3. Poor, with some technical defect but still acceptable for classification purposes
4. Unacceptable

If the technical quality of a radiograph is not Grade 1, the technical defects should be commented upon.

Standard Radiographs

To enhance consistency in the application of its classification system, the ILO has made available to physicians sets of standard chest radiographs, which illustrate various stages of pneumoconiosis and which have been codified by an international panel of experts. These films provide examples of the classification system and are useful for comparison purposes when a physician examines a series of chest films. The availability of these standard films has been an important contribution to occupational medicine. They may be obtained in the United States at a cost of $275 per set from the International Labour Organization, 1750 New York Avenue, NW., Washington, DC. 20006.

Full size reproductions of pertinent sections of the standard films are illustrated in Figures I-15 through I-19. These examples provide graphic demonstrations of small opacity profusion, size, and shape, and attributes of large opacities and pleural thickening defined in prior sections of this chapter.

TRAINING OF PHYSICIANS AND TECHNOLOGISTS

The usefulness of any medical procedure is markedly dependent upon the skills of the individual performing the technical work involved in the procedure and of the physicians who interpret the procedure's derived information. For that reason, the National Institute for Occupational Safety and Health (NIOSH) has been vitally interested in the training and professional standards of physicians and radiographic technologists who participate in its pneumoconiosis programs. For many years, NIOSH, with the assistance of the American College of Radiology, has provided radiologists, chest physicians, occupational health specialists, and their associated technologists short courses (of several days' duration) designed to improve the skills of these individuals both in producing and classifying chest radiographs. The courses are offered at frequent intervals throughout the United States to enable as many individuals as possible to take them.

Courses designed for physicians have been particularly effective. Over 2,500 doctors in a variety of specialties have attended these courses since their inception in the early 1970's. Those who attend one or more of the courses are designated as "A" readers by NIOSH. All of the physicians who participate in its pneumoconiosis programs are "A" readers.

At about the time its training programs for physicians were begun, NIOSH, as well as the Social Security Administration, began the practice of multiple readings of chest radiographs submitted to them by coal workers seeking benefits under the 1969 Federal Coal Miners Health and Safety Act (PL 91-713). Although this practice has been frequently misunderstood, it was instituted with the single purpose of improving the validity of medical information gained from these radiographs. Physician inconsistency can occur in the interpretation and classification of chest radiographs for pneumoconiosis; one of the methods by which such inconsistency can be reduced is the process of multiple readings of films. It is a meritorious practice: it not only benefits the coal miner by increasing the value of information provided by his chest radiograph, it also protects the public against fraudulent reports of disease that are occasionally submitted for adjudication. For these reasons, the practice of multiple reading has been mandated by NIOSH regulations.

In an effort to assure that readings of coal workers' chest films are performed by physicians having the highest possible credentials, NIOSH, in 1973, contracted the Johns Hopkins School of Medicine to develop an examination the Institute could use to test the proficiency of physicians employing the ILO Classification System. Since that time, the examination has been given to over 200 physicians, about 120 of who have been given passing (i.e., 50 or better) grades (13). Those who have passed are called "B" readers and, unless their skill decays from disuse, collectively constitute a superb resource of established competence, available for the evaluation of the increasing number of chest radiographs of individuals who may have been occupationally exposed to hazardous levels of inorganic dusts.

Periodically, the merits of using properly trained lay persons to classify chest radiographs in accordance with the ILO system are considered. If this were practical, it would reduce the burden on physician manpower and might reduce costs. A number of experiments have been carried out to determine the effectiveness of such readers after an appropriate training period. The results of these tests are encouraging. In a recent experiment in the United Kingdom, a group of lay readers, after a period of one year's training, performed as well as a group of experienced physician cohorts (10).

Although training programs developed to augment physician proficiency in the use of the ILO Classification System have been successful, the same cannot, regretfully, be said of efforts to improve the skills of technologists in producing chest radiographs of consistently high quality. Currently, upward of 10% to 25% of the chest films submitted to the Department of Labor and the Social Security Administration are unreadable for technical reasons and many more are less than satisfactory. This is particularly reprehensible because a high proportion of readable films can be achieved given proper equipment, training, and administrative control.

The problem is not only a matter of technologist skill, but of the supervision technologists receive from physicians for whom they work. Since many physicians, including radiologists, receive little or no training in the technical aspects of radiography, their supervision is often of doubtful value. The problem is particularly serious because the radiographic characteristics of the human chest are such that a technologist has precious little latitude for error in estimating the proper exposure to be given a particular patient during chest radiography.

Much greater effort must be expended on radiographic technology training, not only for the technologist, but for the radiologist and practicing physician who uses radiographic equipment as well. All government agencies having responsibility for the administration of coal workers' benefits must establish, as rapidly as possible, minimum technical standards for personnel who wish to provide chest radiographs to them. Some years ago, NIOSH developed and implemented the use of a series of standards which have been instrumental in substantially reducing the number of unreadable films submitted to it (less than 1%). Other government agencies, which have not yet established similar standards of acceptability, should do so with all deliberate speed. Without such efforts, and the will to apply them rigorously, coal workers, as well as the taxpaying public, will continue to suffer inconvenience and loss.

OTHER RADIOGRAPHIC TECHNIQUES USEFUL IN THE EVALUATION OF PNEUMOCONIOSIS

Limitations of Conventional Radiographic Methods

Radiographic methods primarily record anatomical structure. With limited exception, they do *not* record function. Information provided by a chest radiograph on lung structure and on pathological changes that may exist within them is more useful than information on how the lungs may be functioning. In short, the chest radiograph is better in evaluating pathological characteristics of disease than in assessing any impairment the disease may have caused.

These limitations of chest radiography in the evaluation of pulmonary impairment are not difficult to understand. In pneumoconiosis, the disease, particularly in its early stages, is frequently confined to small portions of the lungs (e.g., the upper lobes); large segments can be relatively unaffected. Unaffected regions are likely to function reasonably well, and therefore, regardless of how extensive the disease may be in the diseased zone, pulmonary function may not be significantly impaired. On the other hand, there are times when the disease initially involves much of the lung parenchyma with fibrotic changes that may not be impressive radiographically, but because they are so widespread, may impair function and cause disability relatively early.

The physiological limitations of the chest radiograph should in no way deprecate its value —either from a clinical or public health standpoint—in the evaluation of persons suffering from pneumoconiosis. Its objectivity in accurately and reliably assessing the disease's pathological anatomy is unequalled. Often it represents the best data available on the clinical status of a patient.

Other Radiographic Techniques

The simple chest radiograph, taken with the radiation projected through the subject in a posteroranterior direction, is the keystone of all radiographic examinations of the chest. However, there are occasions when a more extensive examination is called for. For instance, pleural thickening can be detected most easily when seen in profile. Therefore, when localized thickenings exist, as is frequently the case in asbestosis, it may be desirable to take oblique and lateral views of the chest in an effort to bring the lesion into profile.

When pneumoconiosis is complicated by coexisting disease, there are additional radiographic measures that may be useful in evaluating the nature and extent of the pathological processes and their relationships. One of these is tomography, a technique in which thin slices of pulmonary tissues are recorded in cross-section or longitudinally. The images may be presented either in conventional or computerized form. When many such films are made, each depicting a different section of the lungs, pulmonary architecture can be displayed in remarkable detail and without the confusing, superimposed patterns of other structures. The technique is particularly valuable when pulmonary cavities and masses are to be evaluated.

Another technique, useful in the evaluation of bronchial disease, is bronchography. In this procedure, radiopaque materials are instilled or blown into the bronchial tree to demonstrate irregularities, dilations, and obstructive lesions of the respiratory system.

Finally, a battery of radiological tests employing radioactive nuclides has been devised in recent years to study vascular problems associated with the lungs. Some of these show promise in the evaluation of pulmonary function.

All together, radiologic procedures constitute an enormously valuable group of diagnostic tools for use by clinicians and public health physicians when dust-related occupational disease is evaluated. One may expect the number and scope of these techniques to become even greater in the years ahead as medicine profits from this fast-growing science.

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